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㊽Title of the Invention Cooling System for a Linear Motor

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SPECIFICATION

1. Title of the Invention

Cooling System for a Linear Motor

2. Claim

A cooling system for a linear motor, comprising a winding type stator provided with an armature having slots made therein, in which this armature includes a base portion and a plurality of teeth, clearances are provided between two adjoining teeth, a plurality of windings are partially arranged in the clearances, a first and a second clearance have at least a first and a second cooling tube disposed in them, which extend from one side to the other side of the armature, and a coolant feeding system is provided to supply the first and the second cooling tube with coolant.

3. Detailed Description of the Invention

(Industrially Applicable Field)

The present invention relates to an electric mechanical system, and more

particularly, a cooling system for a linear motor.

(Prior Art)

All the electric machinery undergoes heating in its material owing to resistive eddy current loss incurred thereby. Such heating restricts the maximum performance which can be achieved by the electric machinery. The eddy current loss and heating incidental thereto can be mitigated by using thin and mutually insulated layers to form any part of the machinery which can easily be subjected to such loss. In the current-conductive members, the resistive heating can be limited by enlarging the diameters of the conductive members to the utmost of the spatial capacity of the machinery.

In the linear motor disclosed in the corresponding U.S. Patent Application No. 383,351 (already allowed, but its letters patent yet unissued), a smaller number of permanent magnets are arranged along the linearly movable member, and a great number of armature windings which have correlative operation with the permanent magnets are disposed along the linear axis. This allows at least partial solution of both problems of the eddy current and the resistive heating. A commutator means mounted so as to move together with the permanent magnets keeps only armature windings active which are located within the spheres of the magnetic effects of the permanent magnets, and leaves the remaining armature windings inactive . If a linear motor is provided with an armature comparable to the length of a movable member which includes permanent magnets, or if a movable member remains substantially constant in its movement, a zone in which an eddy current and resistive heating take place incessantly moves along the linear axis. Therefore, any linear-motor portion in which the armature windings are inactive is furnished with a substantial opportunity in which it is radially or convectionally cooled to diffuse heat

therefrom into the air.

If a linear motor is provided with an armature of length which substantially approximates that of the movable member, or if a linear motor operates such that the movable member remains held in the substantially same position while it continuously applies substantial electric power to the movable member, the armature of inactive winding may undergo an increase in heat which exceeds the maximum limit endurable thereto. <HERE, TRANSLATION INTO ENGLISH IS OMITTED BECAUSE THE CORRESPONDING JAPANESE-LANGUAGE SENTENCE IS SO VAGUE OR UNCLEAR IN ITS MEANING AS TO PREVENT ITS COMPLETE UNDERSTANDING.) In general, the conventional type armature winding can endure a temperature of up to approximately 300°F.

(Problem to be Solved by the Invention)

Electric current which flows through the electric conductors included in the windings generates resistive heating, and eddy-current heating takes place in the structure having slots made therein. For this reason, the linearly extending portions of the windings can not diffuse heating from them, and the maximum time for which the linear motor continues to operate is limited by the amount of heat which can be diffused from such linearly extending portions located in the clearances between the protrusions.

(Means to Solve the Problem)

It is an objective of the present invention to provide a cooling system for a linear motor which overcome the drawback of the prior art.

It is another objective of the present invention to provide a cooling system for a linear motor, which is constructed such that it is equipped with an armature provided

with slots therein and determined in its extending course between adjoining teeth to allow a coolant feeding tube to absorb heat from the winding of the armature and the structure having slots made therein.

It is a further objective of the present invention to provide an S type single-directional cooling system for the armature of a linear motor, in which S type cooling tubes are fitted in clearances between every two adjoining teeth in the armature to allow coolant to pass at least once along the armature in the longitudinal direction thereof.

It is a still further objective of the present invention to provide a coolant feeding and returning S type cooling conduit system for the armature of a linear motor, in which S type cooling tubes are fitted in clearances between every two adjoining teeth in the armature to allow coolant to pass along the armature in the first longitudinal direction thereof and next in the reverse direction of the first longitudinal direction.

It is a yet another objective of the present invention to provide a cooling system for the armature of a linear motor, in which a ladder type cooling system includes a plurality of substantially parallel cooling tubes located between adjoining teeth in the armature, and is constructed such that coolant is allowed to pass between the inlet header of the tubes on one side of the armature and the outlet header of the tubes on the other side of the armature.

In brief, the present invention provides a cooling system in which cooling tubes are fitted in the clearances between every two protrusions in the armature of a linear motor which is provided with slots. In the first preferred embodiment of the present invention, coolant flows in parallel through a plurality of cooling tubes which connect the inlet header to the outlet header. The outside flow of the coolant may be either of

the open type or of the closed type. In the second preferred embodiment of the present invention, the S type cooling system allows coolant to flow continuously from one end of the armature provided with slots to the other end thereof through the cooling tubes which connect the ends of the armature. In the third preferred embodiment of the present invention, the S type fluid passage of the cooling system is constructed such that coolant is fed and returned.

According to the preferred embodiments of the present invention, in a linear motor which comprises the winding type stator provided with the armatures having slots made in them, the armatures with slots respectively comprise the base portion and a plurality of protrusions in a tooth-shaped configuration, there is provided a clearance between every two adjoining protrusions, the clearance has a plurality of windings partially arranged therein, the first and the second clearance are provided with at least the first and the second cooling tube in them which extend from one side to the other side of the armature, a coolant feeding mechanism is formed to supply the first and the second cooling tube with coolant, whereby there is provided a cooling system for a linear motor.

The foregoing and other objectives, characteristics and advantages of the present invention will be apparent from the following description as well as the accompanying drawings. In the drawings, corresponding components are designated by the same reference numerals.

(Operation)

Coolant is passed through the cooling tubes fitted in the clearances between every two protrusions of the armature with slots in a linear motor, to thereby absorb heat from the linearly extending portions of the windings in the clearances and from

the armature with slots.

(Preferred Embodiments of the Invention)

Referring to Figure 1, there is depicted a linear motor generally at 10, which has a cooling system according to the present invention adapted therefor. A channel bar 12 in a U-shaped configuration is mounted on a fitting surface 14 such as a surface in a positioning table (not shown). A winding type stator 16 is arranged within the groove 12 in a U-shaped configuration. A movable element 18 is disposed such that its underside faces the upper surface 20 of the winding type stator 16.

The moving element 18 is supported by means of a conventional mechanism (not shown) such as a positioning table which allows it to move along a linear axis in parallel with the axes of the channel bar 12 and the winding type stator 16 as shown by a double-headed arrow 22, such that the moving element 18 is held in its underside which adjoins the upper surface 20 of the winding type stator without coming into contact with the upper surface 20 of the winding type stator.

Figure 2 shows a partial side view of the winding type stator 16 and the movable element 18, in which the U-shaped channel bar 12 is removed from the linear motor shown in Figure 1 so that the stator 16 and the movable element 18 inside it can be best seen. The winding type stator 16 includes an armature 24 with slots made therein which is made of a plurality of thin layers electrically insulated to one another by using a conventional method (one of these layers illustrated). The armature 24 with slots made therein comprises a base portion 26 provided with a plurality of teeth 28, and there is a clearance between every two adjoining teeth. A plurality of windings 32 extend along and through the respective clearances 30 in their linearly extending portions (not shown), and their crooked end portions 34 are wound around the base

portion 26 such that the linearly extending portions are connected end to end.

The moving element 18 includes a carrier 36 which has a plurality of permanent magnets 38 of alternating magnetic poles secured on its underside, which are opposed to the upper surface portion 20 of the winding type stator 16.

The carrier 36 is fixed on a suitable guide means such as a positioning table which supports, for example, the moving element 18, and moreover, guides it so as to move along the linear axis. As detailed in my prior patent to be referred to, a winding 32 is continuously fed with power of amplitude which is sufficient to move the moving element 18 with any desirous force and in the direction as desired.

The illustrated embodiment of the present invention only shows a pair of three windings 32 arranged to be used by means of a three-phase type control apparatus. Those skilled in the art might consider it desirable that more pairs of windings are shown. However, in order to obtain definite depiction, other pairs of three windings are omitted from the illustration.

The electric power created by the linear motor 10 is in relation to the electric current which flows through the conductors included in the windings. Any increased electric current generates increment in eddy-current heating at the armature 24 with slots made therein, and resistive heating in the windings. The resistive heating is hardly diffused from the linearly extending portions of the windings 32 located in the clearances between every two teeth, and this is particularly unfavorable to the operation of the linear motor. Therefore, the maximum period of time for which the linear motor 10 is allowed to continuously operate is limited according to the amount of heat which can be diffused from the linearly extending portions of the windings located in the clearances 30.

Figure 3 shows a part of a linear motor 40 in which the winding type stator includes the armature with slots made therein which is similar to that shown in Figure 2 with the exception of cooling tubes 44 located in the clearances located between at least some teeth. Easily usable gaseous or liquid coolant which flows through the cooling tubes 44 absorbs heat from the linearly extending portions of the windings 32 located in the clearances 30 between the teeth and from the armature 24. The absorbed heat decreases a rise in temperature which is incurred by the winding 32 with respect to a predetermined value of the electric current, thereby allowing the electric current to be enhanced. As a result, strong electric power is produced within the limits of the highest temperature which can be withstood by the winding type stator 42 and particularly the windings 32.

Referring to Figure 4 in which the armature 24 with slots made therein is shown by a broken line, a ladder-shaped cooling conduit system 46 comprises an inlet header 48 connecting the flows of the coolant in parallel which are received at all the cooling tubes 44 located in the respective clearances 30 from some easily usable source of supply. The coolant passes through the cooling tubes 44 to an outlet header which discharges the coolant. The outside flow system (not shown) of the coolant to the ladder-shaped cooling conduit system can be of the open type in which water or any other similar fresh coolant is continuously acquired from a source of supply therefor, and the coolant discharged from the ladder-shaped cooling conduit system is passed to a drainage system.

Alternatively, the outside flow system of the coolant may be of the closed type in which at least some of the heat absorbed by means of the cooling tubes 44 is removed from the cooling tubes 44, or the coolant flowing through them before the coolant is

returned to the inlet header 48. In a preferred embodiment of the outside coolant flow system according to the present invention, a heat exchanger (not shown) is used to transmit absorbed heat to an outside medium. To give an alternative example of this outside coolant flow system, water as coolant may be passed through a heat exchanging coil through which the ambient air flows. As another alternative example of the closed type coolant flow system, a mechanical cooling system may be applied in which for example, Freon or any other similar coolant is expanded by using steam, is passed through the cooling tubes 44, and is compressed and condensed in a condenser so as to be liquefied before being returned to the inlet header 48.

All the cooling tubes 44 are shown with the same dimensions. However, they are not necessarily required to be identical in their dimension to one another. Any place adjacent to the suction port or the discharge port for the coolant has a tendency to allow a greater amount of coolant to flow through the cooling tube than any place distant from the suction port or the discharge port for the coolant. In order to obviate this tendency, the cooling tubes 44 are enlarged in their diameters along the ladder-shaped cooling conduit system to achieve substantially equivalent heat absorbing capability of the respective cooling tubes 44. Instead of the increase in the diameters of the cooling tubes 44, the cooling tubes 44 can be arranged such that orifices which influence the flow rates of the coolant fed to the individual cooling tubes are changed in their sizes, thereby achieving a similar effect in which the cooling tubes 44 respectively obtain substantially equivalent capacity to absorb heat.

In some of the preferred embodiments, the linear motor 40 can be arranged to concentrate an unequivalent amount of heat in a predetermined place of the armature 24 formed with slots therein. For example, the linear motor 40 can be started up

constantly from its inherent position. In this case, the starting electric current is several times larger than the operating electric current, and therefore, the amount of heat which occurs in the neighborhood of the inherent position exceeds by far that taking place in any other places of the armature 24 with slots.

The ladder-shaped cooling conduit system 46 may include equipment which increases its capacity to absorb heat adjacent to the inherent position. If the original position is located at an end portion of the armature 24 with slots which is shown at the upper portion of the cooling apparatus in Figure 4, the cooling tubes 44 within some initial clearances 30 are made with their diameters enlarged so as to be greater in the diameters than those within the other clearances, or <HERE, TRANSLATION INTO ENGLISH IS OMITTED BECAUSE THE CORRESPONDING JAPANESE-LANGUAGE SENTENCE IS SO VAGUE OR UNCLEAR IN ITS MEANING AS TO PREVENT ITS COMPLETE UNDERSTANDING.)

Referring to Figure 5, there is shown the armature 24 formed with slots, which is provided with a single-directional S type cooling conduit system 52 allowing the coolant to flow from the inlet tube 54 to the outlet tube 56 through the cooling tube 44 located such as to pass through each clearance 30. The adjoining cooling tubes 44 which form the S type cooling conduit system are jointed with one another by means of end tubes 58.

The outside coolant flow of the single-directional S type cooling conduit system 52 may be of the open type or the closed type as in the prior embodiment described in the foregoing.

Referring to Figure 6, a coolant feeding and returning S type cooling conduit system 60 uses two cooling tubes 44 in each clearance. An outflow side cooling tube 44

receives the coolant from the inlet tube 54 in the same way as in the embodiment of the present invention which is shown in Figure 5. A coolant returning loop 62 allows the coolant to be returned to the coolant returning side cooling tube 44 which returns the coolant to the outlet tube 56 to guide it to the drainage or the heat exchanger. This embodiment of the coolant feeding and returning type cooling conduit system 60 possesses an advantage in which the coolant flowing therethrough is substantially even in its temperature grade regardless of the heat distribution along the armature 24 formed with slots. Therefore, this coolant feeding and returning S type cooling conduit system is effective to set the substantial applying scope of the linear motor.

In a great number of kinds of linear motors, there are sufficient spacings for the linearly extending portions of the cooling tube 44 and the winding 32 in each clearance 30 between the protrusions. In an alternative embodiment of the present invention which is shown in Figure 7, at least some clearances 30 are provided with notches 64 in their bottom portions, which have the cooling tubes fitted into them, to thereby allow the cooling tubes 44 to be contained in the clearances 30. In this embodiment of the present invention, there are provided the additional contact areas of the cooling tubes 44 with a base portion 26, thereby enhancing the capacity of the cooling tubes 44 to absorb heat from the linearly extending portions of the windings 32.

Instead of the notches 64 which are provided as shown in Figure 7, the base portion 26 may be formed with holes (not shown) in a circularly shaped configuration which have the cooling tubes 44 passed and fitted through them. The holes in a circularly shaped configuration may be made at the same time when a thin layer is formed to produce the armature 24 provided with slots.

Having described some preferred embodiments of the invention with reference

to the accompanying drawings, it is to be understood that the invention is not limited to those precise embodiments, and that various changes and modifications may be effected therein by one skilled in the art without departing from the scope of the invention as defined in the appended claims.

The preferred embodiments of the present invention which are described in the foregoing will now be re-arranged and itemized.

(1) A cooling system for a linear motor, comprising a winding type stator provided with an armature having slots made therein, in which this armature includes a base portion and a plurality of teeth, clearances are provided between two adjoining teeth, a plurality of windings are partially arranged in the clearances, a first and a second clearance have at least a first and a second cooling tube disposed in them, which extend from one side to the other side of the armature , and a coolant feeding system is provided to supply the first and the second cooling tube with coolant.

(2) A cooling system for a liner motor as described in the preceding Item (1), in which the coolant feeding system is in parallel with at least all of the first and the second cooling tube.

(3) A cooling system for a linear motor as described in the preceding Item (2), in which the coolant feeding system comprises an inlet header which feeds coolant to all of the first and the second cooling tube, and an outlet header which receives coolant from all of the first and the second cooling tube.

(4) A cooling system for a linear motor as described in the foregoing Item (1), in which the coolant feeding system comprises at least a mechanism which feeds coolant continuously to at least some of the first and the second cooling tube.

(5) A cooling system for a linear motor as described in the preceding Item (4), in

which the first and the second cooling tube, and the coolant feeding system together form a single-directional S type cooling conduit system.

(6) A cooling system for a linear motor as described in the preceding Item (5), in which the single-directional S type cooling conduit system comprises at least a single end tube which receives coolant from the first cooling tube, and feeds the coolant to the second cooling tube.

(7) A cooling system for a linear motor as described in the preceding Item (6), in which the single-directional S type cooling conduit system comprises an inlet tube which feeds coolant to the first cooling tube, and an outlet tube which receives the coolant from the second cooling tube.

(8) A cooling system for a linear motor as described in the foregoing Item (4), in which at least the first and the second cooling tube, and the coolant feeding system together form a coolant feeding and returning S type cooling conduit system.

(9) A cooling system for a linear motor as described in the preceding Item (8), in which the coolant feeding and returning S type cooling conduit system comprises a coolant returning loop, the coolant returning loop receives the coolant from the first cooling tube, and feeds the coolant to the third cooling tube, the first and the third cooling tube are arranged in the clearance between the first protrusions, thereby allowing the first clearance to be cooled by means of the coolant which flows forwards and rearwards.

(10) A cooling system for a linear motor as described in the foregoing Item (1), in which the first and the second clearance have notches made within them to fit the first and the second tube in them.

(11) A cooling system for a linear motor as described in the foregoing Item (1), in

which the first and the second cooling tube comprises a mechanism which provides capacity to absorb a variety of heat.

(12) A cooling system for a linear motor as described in the preceding Item (11), in which the mechanism which provides capacity to absorb a variety of heat is diverse in its diameter with respect to the first and the second cooling tube.

(13) A cooling system for a linear motor as described in the preceding Item (11), in which the mechanism which provides capacity to absorb a variety of heat includes a different number of cooling tubes in the first and the second clearance.

(Effect of the Invention)

In the arrangement of the present invention, coolant flows through the cooling tube or tubes located at the bottom portions of the clearances 30 between the protrusions of the armature having slots made therein, and this coolant absorbs heat from the linearly extending portion of the winding 32, thereby reducing an increase in a temperature incurred by the windings 32 under a predetermined value of the electric current through the windings 32 whereby the electric current is enhanced in its value. As a result, strong electric power is created within the limits of the highest temperature which is endurable to the winding type stator 16 and particularly the windings 32.

4. Brief Description of the Drawings

Figure 1 is a perspective view of a linear motor according to a preferred embodiment of the present invention. Figure 2 is a side view of the linear motor shown in Figure 1. Figure 3 is a side view of the linear motor shown in Figure 1, which shows the arrangement of cooling tubes within clearances. Figure 4 is a plan view of an armature having slots made therein, depicted in Figure 3, which shows the flow

passages of cooling tubes and headers of a cooling system in a ladder-shaped configuration. Figure 5 also is a plan view of the armature with slots, depicted in Figure 3, which shows the flow passage of the cooling tube in a single-directional S type cooling system. Figure 6 also is a plan view of the armature with slots, depicted in Figure 3, which shows the flow passages of the cooling tubes of a coolant feeding and returning S type cooling conduit system. Figure 7 is a side view of the linear motor depicted in Figure 1, which shows the arrangement of the cooling tubes in notches made in the clearances.

10, 40......Linear Motor

16, 42......Winding Type Stator

18......Movable Element

24......Armature having slots made therein

26......Base Portion

28......Teeth

30......Clearance

32......Winding

36......Carrier

38......Permanent Magnet

44......Cooling Tubes

46......Ladder-shaped Cooling Conduit System

48......Inlet Header

50......Outlet Heade

52......Single-Directional S Type Cooling Conduit System

60......Coolant Feeding and Returning S Type Cooling Conduit System

64......Notch